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Structural setting of the Hammam Faraun block, eastern side of the Suez rift

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ABSTRACT

Field mapping of the Hammam Faraun block indicates its predominant NE dip and the existence of some subblocks with anomalous dip direction(s). The NE dip of the block resulted from rotation on NW and NNW-oriented listric normal faults at the eastern boundary of the Suez rift. A horizontal subblock apparently glided on the gently dipping segment of one of these listric faults. Local SW dip in other subblocks is related to drag on major faults.

Folding plays a subordinate role in the deformation of the Hammam Faraun block while faulting is the predominant structure. NW, NNW, E-W, and NNE fault sets exist. Slickensides indicate that the NW faults are normal or right-lateral diagonal slip, the NNW faults are only normal, and the NNE faults are normal or diagonal-slip (right- or left-lateral).

The ENE-WSW extension that opened the rift formed the NNW-oriented faults and rejuvenated a pre-existing NW-oriented fault at the western boundary of the Hammam Faraun block forming a diagonal-slip fault (the Hammam Faraun fault) with a major dip-slip (normal) component and subordinate right-lateral strike-slip component. Local extension due to the strike-slip movement on the Hammam Faraun fault apparently formed the N-S to NNE oriented faults in its vicinity. Stratigraphic and structural field data indicate that the onset of rifting took place before the deposition of the Lower Miocene Nukhul Formation. Another movement took place after the deposition of the existing part of the Rudeis Formation.

INTRODUCTION

The 300-km long Suez rift can roughly be divided into three longitudinal parts, the middle of which is occupied by the Gulf of Suez. The eastern and western parts of the rift are exposed in west Sinai and the Egyptian Eastern Desert respectively. Excellent exposures in these areas help study the structural characteristics of the rift. The rift itself was divided into three transverse provinces (mega-blocks) by Moustafa (1976). These are the northern, central, and southern provinces; each has a characteristic direction of dip (the three dip provinces of Moustafa 1976). Each of these dip provinces is in fact a half (asymmetric) graben bounded on one side by a major listric (curved) normal fault and on the other (updip) side by another fault of much

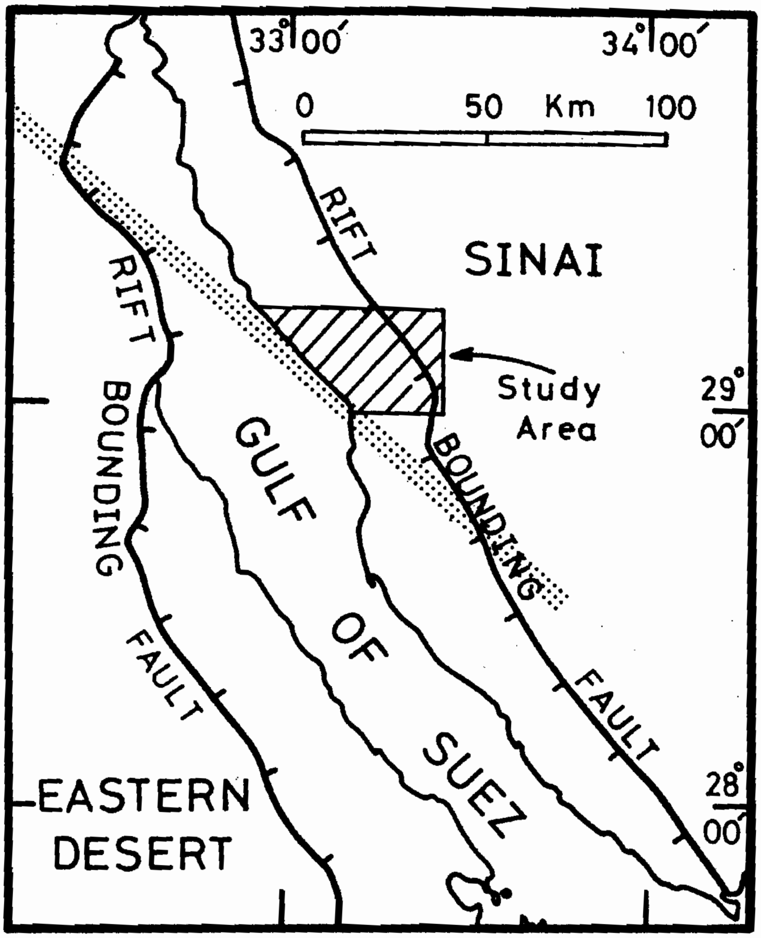


Fig. 1. Location map of the study area showing a NW-oriented fault belt (stippled) identified by Moustafa and El Shaarawy (1987) in the northern part of the Suez rift.

smaller throw. Each half graben consists of several fault blocks which were given various names by Robson (1971) and Garfunkel & Bartov (1977). The Hammam Faraun block is one of these blocks and exists on the eastern side of the rift (Fig. 1).

Despite the predominant NE direction of dip of the Hammam Faraun block, local changes in the direction of dip are not uncommon. The block is also bounded on the west by a major NW-oriented fault (the Hammam Faraun fault) that controls the shoreline in many places and has a substantial amount of throw. This fault was proposed by Moustafa & El Shaarawy (1987) to have existed before the Neogene opening of the rift and to have a major effect on the tectonic evolution of the northern part of the Gulf of Suez.

Field mapping on a scale of 1 : 40,000 and detailed structural field study of the Hammam Faraun block were carried out in order to throw light on the cause(s) of the local changes in the dip direction and to study the effect of the Hammam Faraun fault on the other structures of the area.

The mapped area is 845 km^2 (Plate 1) and extends from Latitude 28°59′12″N to Latitude 29°14′27″N. It is bounded on the west by the Gulf of Suez and on the east by the rift-bounding fault.

STRATIGRAPHY

A 2400 m thick sedimentary section exists in the Hammam Faraun block (Fig. 2). It includes 2000 m of pre-Miocene (pre-rift) sedimentary successions and about 400 m of Lower Miocene (syn-rift) section. Basic igneous rocks of Oligo-Miocene age (22–24 m.y. K-Ar age, Steen 1982) exist in the area and affect only the pre-Miocene rocks. A description of the units mapped in Plate 1 is given below.

PALEOZOIC TO LOWER CRETACEOUS ROCKS

Paleozoic sedimentary rocks cover the Precambrian basement in the mapped area and are 321 m thick. They belong to the Um Bogma and Ataqa Formations (Said 1962). The former consists of a sandstone unit overlain by a dolomite-limestone unit with characteristic marine Carboniferous fauna. The latter (younger) formation consists of a thick sandstone unit with plant remains (Ball 1916).

A 250 m thick siltstone and sandstone unit overlies the Carboniferous section and is, according to Barakat *et al.* (1986), Permo(?)-Triassic to Lower Cretaceous. This unit is equivalent to the Qiseib and Malha Formations of Abdallah & El Adindani (1963).

UPPER CRETACEOUS ROCKS

The Malha Formation is overlain by a 127 m thick, highly fossiliferous, marine Cenomanian section (Raha Formation (Ghorab 1961)) which consists of shale, marl, sandstone, and limestone. A fairly thick, predominantly limestone and dolomitic limestone Turonian section (Wata Formation (Ghorab 1961)) overlies the Raha Formation. It has a maximum thickness of 185 m at Gebel Abu Ideimat area. It is overlain by a Lower Senonian, predominantly clastic, section (Matulla Formation (Ghorab 1961)) which is 67 m thick and includes a predominantly sandstone unit at the base and a shale unit at the top.

The Duwi Formation (Youssef 1960) overlies the Matulla Formation and is about 32 m thick. It is Campanian in age and consists of claystones with some phosphatic sandstone, dolomitic limestone, and chert beds. This formation is overlain by a massive chalk unit of Campanian-Maastrichtian age (Sudr Formation (Ghorab 1961)). The thickness of this unit was not measured in the field because of its steep slopes but nearby subsurface data indicate that this unit is about 215 m thick.

PALEOCENE AND EOCENE ROCKS

The Paleocene-Lower Eocene Esna Shale overlies the Sudr Formation and is 51 m thick. It consists of greenish grey shale and a thin limestone ledge near its middle part. It is overlain by a thick Eocene section with a sharp contact except in the

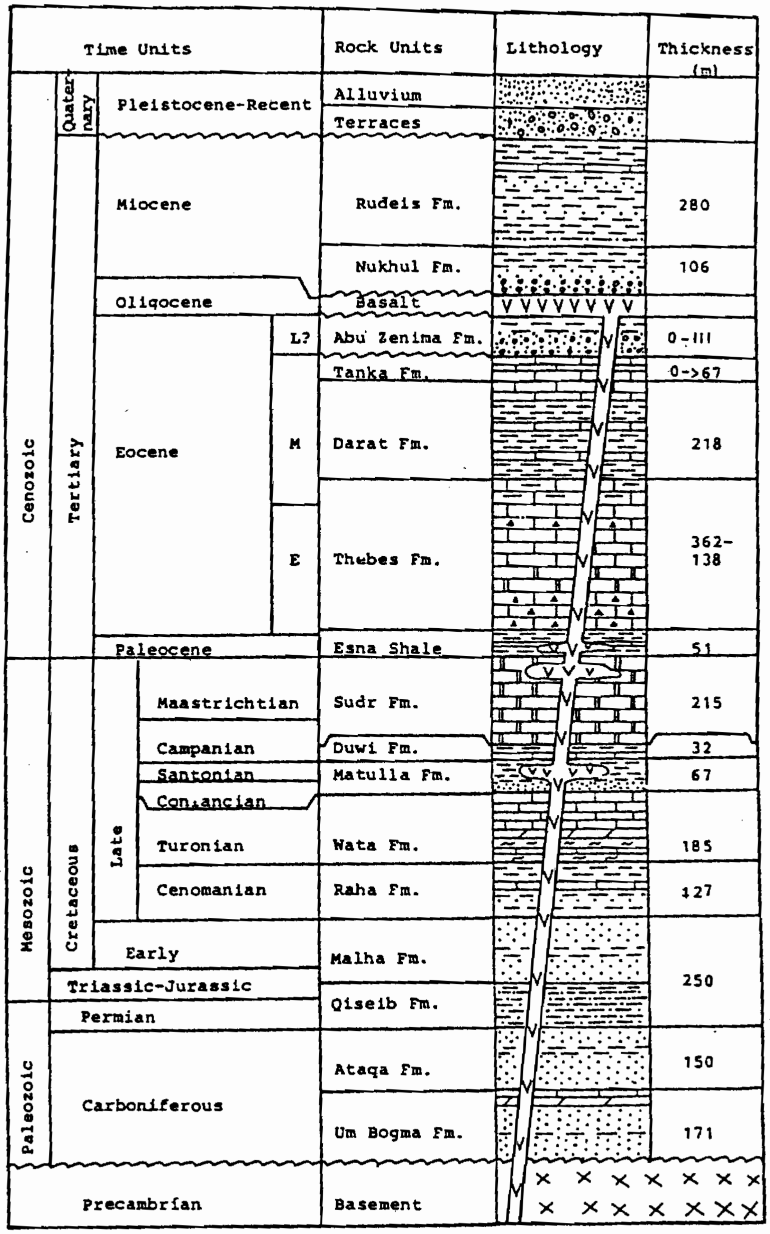


Fig. 2. Composite stratigraphic section of the Hammam Faraun block.

northern part of the area where the contact is gradational and the lithology is somewhat different (e.g. at Gebels Thal and Hammam Faraun).

The lower part of the Eocene section of the area belongs to the Thebes Formation that has an Early to Middle Eocene age (Viotti & El-Demerdash 1969; El-Heiny & Morsi 1986). The Thebes Formation includes three units; a lower limestone unit with chert bands, a middle hard chalky limestone unit, and an upper chalky limestone unit that has chert bands and is marly at the top. The lower unit is mapped as unit Te1 on Plate 1 while the middle and upper units are mapped together as another unit (unit Te2, Plate 1). The facies of this part of the Eocene section is different at Gebels Thal and Hammam Faraun (Abul-Nasr 1987). Giving a new formation name to these rocks in these localities is beyond the objectives of the present study. On the other hand, the thickness of the Thebes Formation changes abruptly in the study area. It is 138 m in Wadi Nukhul (Viotti & El-Demerdash 1969) and 362 m southwest of Gebel Musabaa Salama.

The Thebes Formation is overlain by the Middle Eocene Darat Formation which is 218 m thick and consists mainly of shales and marls with some limestone beds. This formation is equivalent to both the Darat and Khaboba Formations of Viotti & El-Demerdash (1969) which are mapped together as one unit in the present study because of the great similarity between them and the difficulty to map each unit separately in the field. This formation is overlain by the Tanka Formation which is Middle Eocene (El-Heiny & Morsi 1986) or Late Eocene (Viotti & El-Demerdash 1969) and consists of thin interbedded chalky limestone and claystone. Its thickness is 35 m at Wadi Taiyba and 67 m at Wadi Thal. It thickens northward toward Wadi Gharandal and is missing to the south of Gebel Sarbut El Gamal and at Wadi Nukhul. The upper contact of the Tanka Formation is an erosional surface in the Hammam Faraun block. The uppermost part of this formation is less eroded at Wadi Thal.

The Abu Zenima Formation (Hanter 1965) unconformably overlies the Tanka Formation and is Late Eocene (Hume *et al.* 1920), Oligocene (Ansary 1955), questionable Oligocene (Viotti & El-Demerdash 1969), or post-Late Middle Eocene and pre-Miocene (El-Heiny & Morsi 1986). Abul-Nasr (1987) used microfossils to date the lower part of this unit as Early Oligocene. This formation consists of red or purple sandstones and claystones with some conglomerate beds. Contrary to the Tanka Formation, the Abu Zenima Formation increases in thickness southward in the Hammam Faraun block. Its thickness is 20 m at the mouth of Wadi Taiyba, 30 m to the south of Gebel Sarbut El Gamal, and 111 m at Wadi Nukhul. It is missing in the northern part of the area at Wadi Thal, Gebel Hammam Faraun, and the area north of Wadi El Iseila.

OLIGO-MIOCENE IGNEOUS ROCKS

Mafic igneous rocks crop out in the Hammam Faraun area and occupy a stratigraphic position between the pre-rift and syn-rift sedimentary sequences. They exist in the form of basalt flows, dikes, and sills (Plates 1 and 2). The basalt flows of Wadi Taiyba help constrain the age of these igneous rocks. These basalts were extruded above the Abu Zenima Formation whose top is baked. In addition, basalt boulders in the lowermost bed of the overlying Nukhul Formation (Lower Miocene) constrain the age of these basalts as Oligo-Miocene.

Excellent exposures of mafic sills and dikes exist in Wadi Matulla where several sills branch from their feeder dikes. The sills of the Hammam Faraun area occupy a narrow stratigraphic interval extending from the topmost part of the Sudr Chalk to the top of the Esna Shale. The depth of intrusion of these sills is, therefore, estimated to have been 680–750 m below the surface during the Oligo-Miocene.

The mafic igneous rocks mapped in the study area are considered to represent the initial rift-related rocks. They were emplaced during the time interval extending between the end of deposition of the pre-rift sediments and the beginning of deposition of the syn-rift (Miocene) sediments. Angular unconformity between these two series of sedimentary rocks is related to the initial movement and rotation on the rift-bounding, listric normal faults as will be explained later. Field evidence at the mouth of Wadi Taiyba indicates that the basalt flows are parallel to the underlying pre-rift sequences. This perhaps indicates that both were rotated together as a result of the initial fault movements. Therefore, we believe that the Oligo-Miocene igneous rocks of the study area are contemporaneous with the onset of rifting in the Suez rift.

MIOCENE ROCKS

The Lower Miocene rocks of the Hammam Faraun block are about 400 m thick and lie unconformably on the pre-Miocene rocks. They include the Nukhul and Rudeis Formations. The former is 106 m thick at Wadi Nukhul and the latter is about 280 m thick at Gebel Sarbut El Gamal.

The Nukhul Formation consists mainly of coarse clastics with a few claystone beds. It has a basal conglomerate bed which includes basalt boulders, derived from the Oligo-Miocene basalts, and/or chert and limestone boulders and pebbles derived mainly from the Thebes Formation. This conglomerate bed is about 14 m thick at Wadi Nukhul.

The Rudeis Formation is predominantly made up of claystones with some sandstone and limestone interbeds. A few conglomerate beds also exist. A 50–60 m thick limestone unit exists at the top of this formation at Gebel Sarbut El Gamal.

QUATERNARY ROCKS

Thick Quaternary terraces predominate in the northern part of the Hammam Faraun block at Wadis El Iseila and Thal and east of Gebel Hammam Faraun. Quaternary alluvium covers the floors of the wadis, the coastal plain, and the Markha plain.

STRUCTURES

The Hammam Faraun block is highly dissected by faults which are mainly normal and, in a few cases, diagonal-slip. Only one minor NW-oriented thrust exists and affects the Eocene rocks in the northeastern part of the block. Folding, on the other hand, plays a minor role in the structural deformation of the block (Fig. 3).

A total of 175 faults dissect the Hammam Faraun block (Plate 1) and belong to four prominent sets (Fig. 4) which are oriented, in a descending order of predominance: NW (mean orientation N50°W), NNW (mean orientation N15°W), E-W (mean orientation N85°W), and NNE (mean orientation N15°E).

The angles of dip of 72 of these faults were measured in the field. They range between 44° and 90°. The NW and NNW faults have very steep angles of dip (generally more than 60° and reach 90°) while the NNE faults have smaller angles of dip (generally less than 60° and rarely reach 80°).

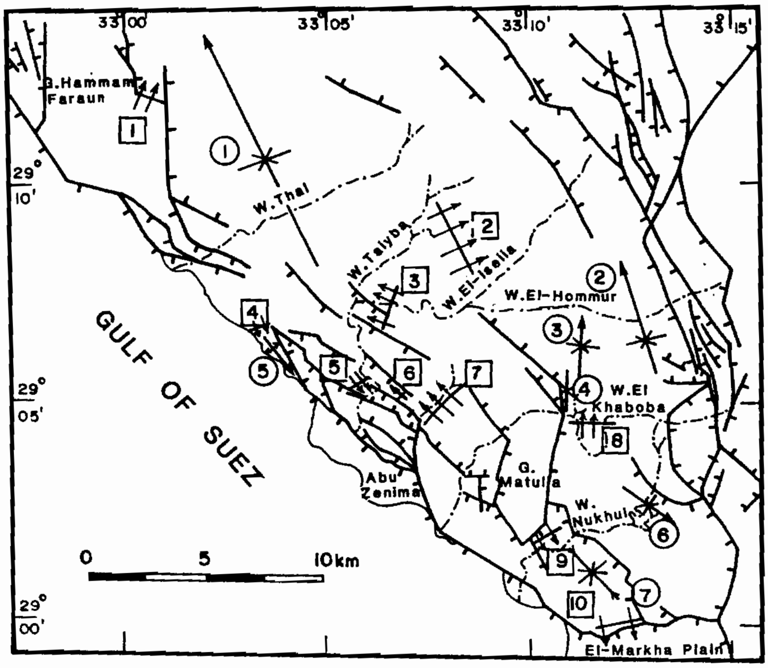


Fig. 3. Folds and monoclines of the Hammam Faraun block. Encircled numbers refer to the following folds: (1) Wadi Thal, (2) Gebel Sarbut El Gamal, (3 & 4) Wadi El Khaboba, (5) Gebel Tanka, (6) Wadi Nukhul, and (7) Bir El Markha. Numbers within squares refer to the following monoclines: (1) Gebel Hammam Faraun, (2) Wadi El Iseila, (3) Wadi Taiyba, (4) Gebel Tanka, (5) West of Taiyba Oasis, (6) Southeast of Taiyba Oasis, (7) Wadi Darat, (8) Wadi El Khaboba, (9) Wadi Nukhul, and (10) Bir El Markha.

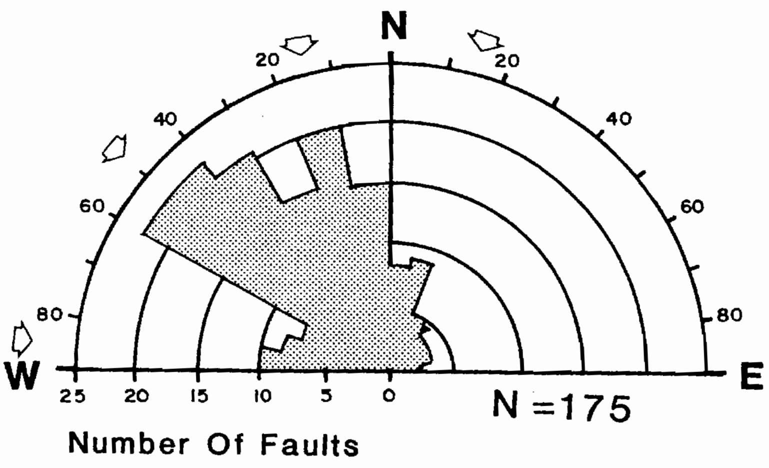


Fig. 4. Rose diagram of the faults of the Hammam Faraun block. Arrows indicate the mean orientations of the prominent peaks.

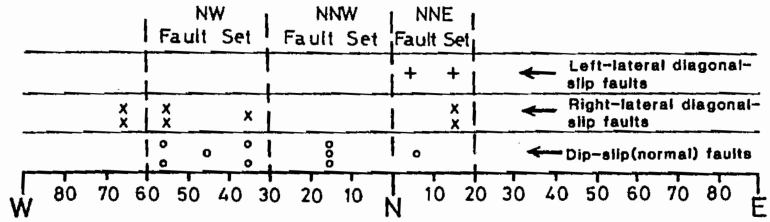


Fig. 5. Sense of slip of 18 faults in the Hammam Faraun block as indicated by slickensides.

The planes of the mapped faults were thoroughly examined in the field. Slickensides were found on 18 of these and indicate that the faults of the NW set are either normal or right-lateral diagonal-slip; those of the NNE set are normal, right-lateral diagonal-slip, or left-lateral diagonal-slip; and those of the NNW set are only normal (Fig. 5).

STRUCTURAL SETTING

The Hammam Faraun block is bounded on the east by the rift-bounding fault that separates it from the rift shoulder where the rocks generally have a near horizontal attitude. The western and southern boundaries of the block are controlled by major faults while the northern boundary lies close to the change in dip regime in the northern part of the Suez rift. This northern boundary is not dealt with in this work and will be the subject of another detailed study.

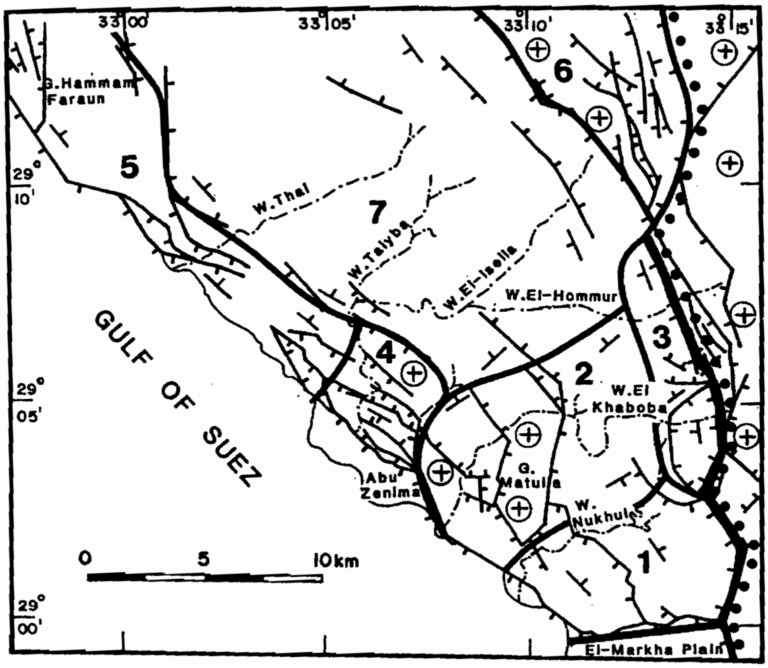
The Hammam Faraun block includes seven subblocks; each has a characteristic dip direction(s) (Fig. 6). The boundaries between these subblocks are generally structural though in a few cases they are not distinct. These subblocks are called the Wadi Nukhul, Gebel Matulla, Gebel Sarbut El Gamal, Wadi Taiyba, Gebel Hammam Faraun-Gebel Thal, Gebel Abu Ideimat, and north-central subblocks.

1. *Wadi Nukhul subblock*

The Wadi Nukhul subblock has a NE dip with pre-Miocene rocks dipping 12–15°, unconformably overlain by gently dipping Miocene rocks. It is bounded on the east, south, and west by major faults.

The eastern boundary faults are oriented NNE and NNW and have throw amounts exceeding 1850 m. Nearly horizontal Paleozoic rocks exist on the upthrown sides of these faults (Plate 2, cross section A-A′) while on the downthrown sides, the subblock dips toward the NNW oriented fault. This apparently indicates that this fault is listric (Shelton 1984). The angular discordance between the pre-Miocene rocks and the gently dipping Nukhul Formation in this subblock indicates that the displacement on the NNW listric boundary fault of the Nukhul subblock preceded and followed the deposition of the Lower Miocene Nukhul Formation.

The southern boundary fault of the subblock is a major ENE-oriented fault whose throw exceeds that of the eastern boundary faults. The Eocene and Miocene rocks on the upthrown side of this fault are dragged and dip steeply southward



• • • RIFT BOUNDING FAULT

Fig. 6. Structural subblocks of the Hammam Faraun block. Dip/strike symbols indicate the direction(s) of dip in each subblock. Encircled crosses designate horizontal attitudes. Numbers refer to the following subblocks: (1) Wadi Nukhul, (2) Gebel Matulla, (3) Gebel Sarbut El Gamal, (4) Wadi Taiyba, (5) Gebel Hammam Faraun-Gebel Thal, (6) Gebel Abu Ideimat and (7) North-central.

forming the Bir El Markha monocline (Plate 1 and Fig. 3). The dragged Miocene rocks of the Nukhul Formation indicate that the last movement on this fault post-dates the deposition of the Nukhul Formation.

The western boundary fault of the Wadi Nukhul subblock is oriented NW and marks the shoreline of the Gulf of Suez in that area. Dragged beds on the upthrown side of this fault are obvious in the field.

The northern boundary of the subblock lies close to Wadi Nukhul itself where a SE-facing monocline and an ENE-oriented fault separate this subblock from the adjacent part of the Gebel Matulla subblock.

Two NW-oriented fault blocks make up the Wadi Nukhul subblock and are separated by a group of faults connected together in a zigzag pattern. These faults are oriented NNW, WNW, and NNE (Plate 1). The throw of this fault system reaches 1100 m in its middle part. The basal conglomerate bed of the Nukhul Formation on the downthrown side fills an old NW-oriented channel parallel to the strike of the nearby fault. This channel occupies the trough of the Bir El Markha syncline (Fig. 3) that was formed by drag on the downthrown side of this fault system. This apparently indicates that the movement on this fault system took place before the deposition of the Nukhul Formation. On the other hand, the NE dip of the Nukhul Formation in this area indicates another movement after the deposition of this formation, at least on the eastern boundary fault of the subblock.

2. *Gebel Matulla subblock*

Rocks in the main part of the Gebel Matulla subblock have horizontal to very gentle attitude. Local tilting toward the adjacent subblocks exists at the boundaries forming a positive (anticlinal) box fold with a very broad, flat crest (Plate 2, cross section X–X′). A NNW-oriented fault forms the western boundary of this subblock. Visible drag on the upthrown side of this fault causes the rocks to dip locally about 45° toward Abu Zenima town. The boundary between this subblock and the Wadi Taiyba subblock, that lies to the northwest, is marked by the Wadi Darat monocline (Fig. 3) as well as NNW and NE-oriented faults (Fig. 6 and Plate 1).

NNE and NNW to NW-oriented faults dissect this subblock. It is also intruded by several mafic igneous dikes and sills. The dikes are oriented N, NNW, NW, and NE. A NNW-oriented normal fault dissects one of the sills on the northern side of Wadi Matulla (Plate 1). The dragged sill indicates that the movement on this fault took place after the intrusion of the sill.

3. *Gebel Sarbut El Gamal subblock*

The Gebel Sarbut El Gamal subblock is a northwesterly-elongated structural low lying on the downthrown side of a major NNW-oriented fault at the rift boundary. The throw of this fault ranges from 1500–1100 m. The subblock has a predominant W to SW dip.

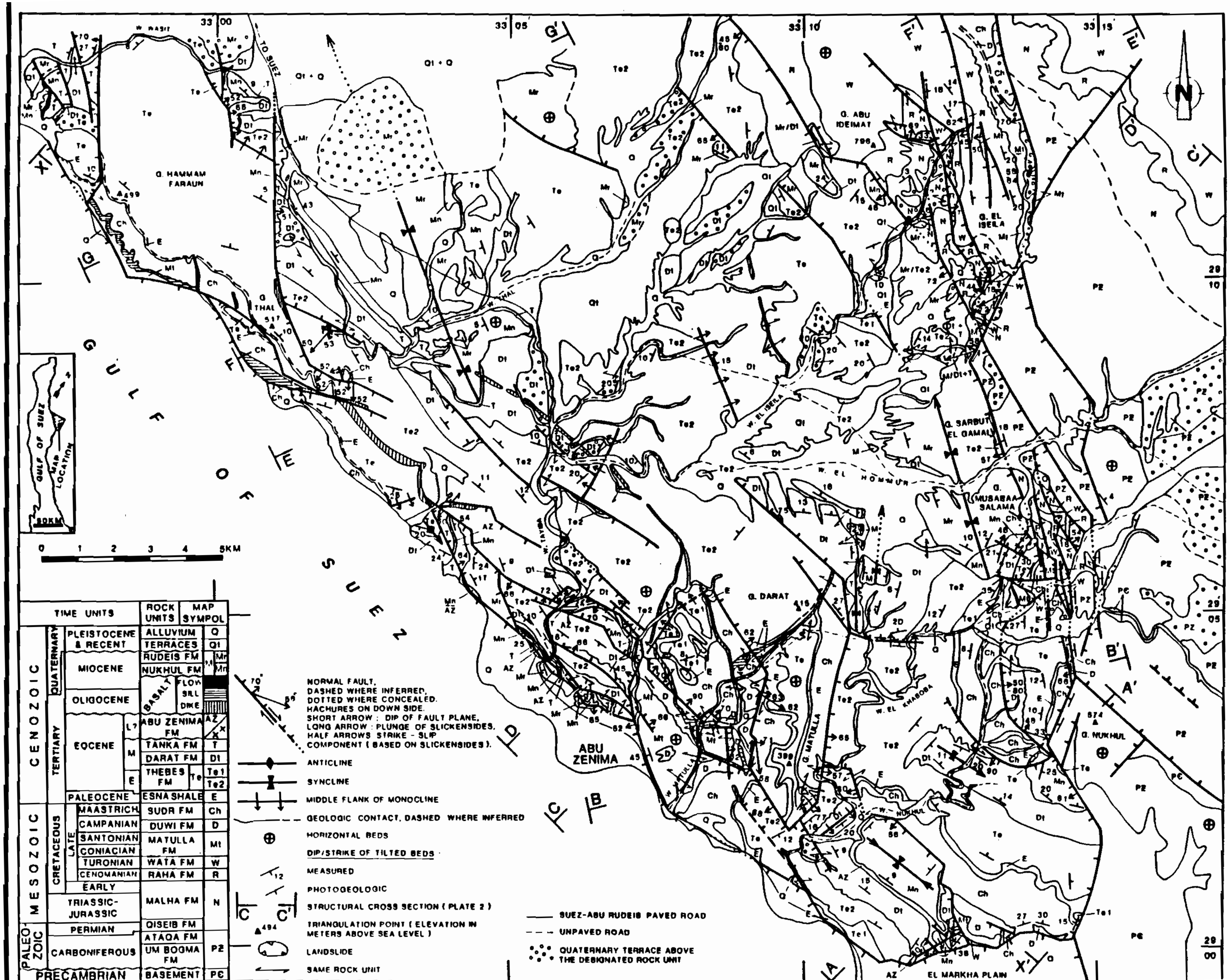
The Miocene rocks in the northern half of this subblock are folded by a NNW plunging syncline. A NW-oriented normal fault dissects the Rudeis Formation in the southern part of this syncline (area west of Gebel Musabaa Salama) indicating that the tectonic activity continued after the deposition of these rocks (Plate 1).

The southern half of the Gebel Sarbut El Gamal subblock is a graben bounded by faults on all sides and lies to the south of Rod Musabaa Salama (Plate 1). It is downthrown about 1100 m on the eastern and southern faults and about 350 m on the western fault. In cross section, the western fault is antithetic to the eastern (major) fault (cross section B-B′, Plate 2). The rocks in this graben dip about 12–19° SW while the area west of the graben has a gentler dip. This probably indicates that this graben block is scooped on the faults that bound it on the NW, W, and SW. The NW-oriented fault on the southern side of this graben has diagonal slickensides indicating a right-lateral strike-slip component.

4. *Wadi Taiyba subblock*

The eastern part of the Wadi Taiyba subblock has a horizontal attitude while its western part dips SW (Plate 1 and Plate 2, cross section D–D′). This SW dip is anomalous compared to the horizontal attitude of the Gebel Matulla subblock that lies to the south, and the NE dip of the Gebel Hammam Faraun-Gebel Thal subblock that lies to the northwest.

This subblock is dissected by several NW-oriented normal faults. The westernmost of these faults has the largest amount of throw and lies along the extension of the coastal fault forming the western boundary of the Gebel Hammam Faraun-Gebel Thal subblock. A NW-facing monocline exists to the southeast of the Taiyba Oasis (Plate 1 and Fig. 3) and lies between the ends of two en echelon NW-oriented normal faults.


GULF OF SUEZ
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UM BOGMA FM
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PRECAMBRIAN
BASEMENT
PC
NORMAL FAULT, DASHED WHERE INFERRED, DOTTED WHERE CONCEALED. HACHURES ON DOWN SIDE.
SHORT ARROW : DIP OF FAULT PLANE, LONG ARROW : PLUNGE OF SLICKENSIDES, HALF ARROWS STRIKE - SLIP COMPONENT (BASED ON SLICKENSIDES).
ANTICLINE
SYNCLINE
MIDDLE FLANK OF MONOCLINE
GEOLOGIC CONTACT, DASHED WHERE INFERRED
HORIZONTAL BEDS
DIP/STRIKE OF TILTED BEDS
MEASURED
PHOTOGEOLOGIC
STRUCTURAL CROSS SECTION (PLATE 2)
TRIANGULATION POINT (ELEVATION IN METERS ABOVE SEA LEVEL)
LANDSLIDE
SAME ROCK UNIT
SUEZ-ABU RUDEIS PAVED ROAD
UNPAVED ROAD
QUATERNARY TERRACE ABOVE THE DESIGNATED ROCK UNIT
G. HAMMAM FARAUN
W. WASIT
TO SUEZ
G. THAL
W. THAL
W. TAYIBA
ABU ZENIMA
G. DARAT
G. MATULLA
W. MATULLA
W. EL ISEILA
W. EL HOMMUR
W. EL KHABOBA
G. ABU IDEIMAT
G. EL ISEILA
G. SARBUT EL GAMAL
G. MUSABAA SALAMA
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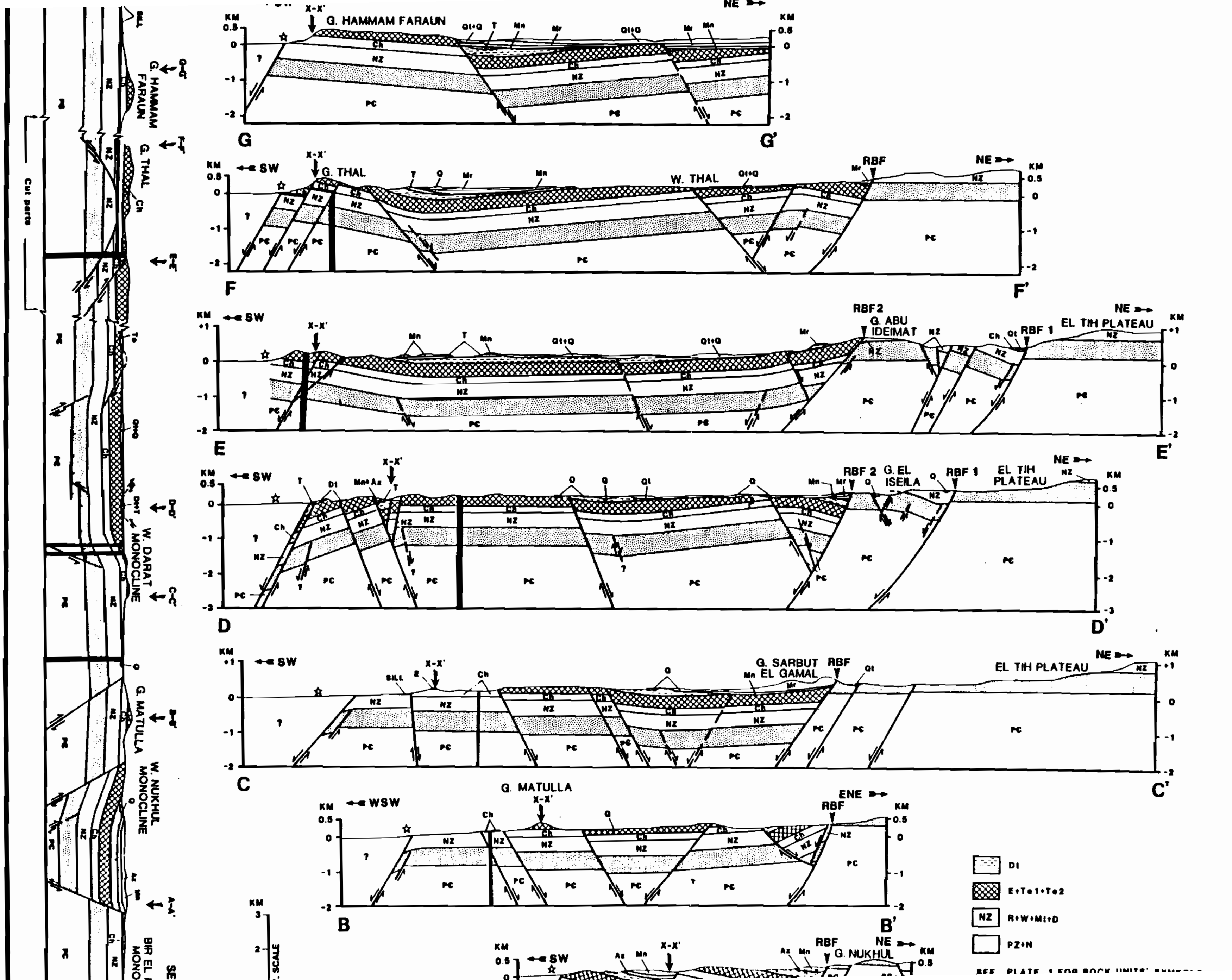
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G. SARBUT EL GAMAL
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EL TIH PLATEAU
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G. MATULLA
RBF
B
B'
G. NUKHUL
W. DARAT MONOCLINE
W. NUKHUL MONOCLINE
Cut parts
Dl
E+Te1+Te2
R+W+Mt+D
PZ+N

A NW-oriented graben is also enclosed between some of these NW-oriented faults and exists at the crest of the flexure connecting the horizontal and the SW-dipping rocks of this subblock (Plate 2, cross section D–D′). This graben ends southeastward against a NW-oriented fault and northwestward against a SE-facing monocline on the western side of the Taiyba Oasis (Fig. 3).

The Wadi Taiyba subblock shows clear evidence for the time of movement on the NW-oriented faults. The Nukhul Formation and the underlying basalt flow are preserved in the NW-oriented graben mentioned above and are similar to those exposed at the mouth of Wadi Taiyba (Plate 1). They were perhaps continuous before the faults dissected them indicating that the last movement on the NW-oriented faults in this area took place after the deposition of the Nukhul Formation. A similar conclusion is reached by observing the westernmost fault in this subblock where the Rudeis Formation is dragged on the downthrown side indicating that the last movement took place after the deposition of these rocks. The Nukhul Formation is also dragged on the upthrown side of the same fault.

5. *Gebel Hammam Faraun-Gebel Thal subblock*

The Gebel Hammam Faraun-Gebel Thal subblock is elongated northwesterly and has a predominant NE dip. It is highly dissected by faults oriented WNW, NW, NNW, and N-S. It is noticeable that the N-S faults are more predominant in Gebel Hammam Faraun itself compared to other parts of the Hammam Faraun block (Fig. 6 and Plate 1). Some of the NW and WNW-oriented faults mark the shoreline of the Gulf of Suez at Gebel Hammam Faraun. A WNW-oriented minor fault exists in Wadi Thal beside the WNW-oriented macrofaults and has diagonal slickensides indicating a right-lateral strike-slip component.

The Gebel Hammam Faraun-Gebel Thal subblock is structurally higher than the subblocks lying to the east and west (Plate 1 and Plate 2; cross sections E–E′, F–F′ and G–G′). Several dikes and sills intrude this subblock. The dikes are oriented N, NW, and E-W.

Two long N-S faults bound Gebel Hammam Faraun on the east and west forming a horst. A moncline exists as a ramp block between the eastern fault and another (smaller) fault of the same orientation at the northeastern corner of Gebel Hammam Faraun (Fig. 3). Also, a graben exists between the western fault and another fault of the same orientation lying to the west of it.

Another graben exists at Gebel Tanka and has a rhomb shape (Plate 1). It is bounded on all sides by NW or NNW-oriented faults. To the northwest of this graben is a SE-plunging anticline on the upthrown side of the major coastal fault of this subblock (Fig. 3).

6. *Gebel Abu Ideimat subblock*

The Gebel Abu Ideimat subblock lies at the northeastern part of the Hammam Faraun block (Plate 1 and Fig. 6). It is bounded on the east by the rift-bounding faults which are NNW and NNE-oriented faults and their throws are 650–700 m. This subblock dips NE toward the NNW-oriented fault while horizontal beds exist on the upthrown side. This apparently indicates that this NNW-oriented fault is listric. NW-oriented faults bound this subblock on the west and their throws are about 1000–1300 m. The angles of dip of these faults are generally small (45–48°) but locally increase to 60° and 66° (Plate 1).

The western part of the Gebel Abu Ideimat subblock has a horizontal attitude and, in cross section, the subblock has the form of a NE-dipping flexure (Plate 2, cross sections D–D′ and E–E′). Several N to NNW-oriented faults exist at the crest of this flexure forming a horst, graben, and step fault arrangement (Plates 1 and 2).

7. *North-central subblock*

The North-central subblock occupies the largest part of the Hammam Faraun block (Fig. 6) and is structurally and topographically lower than the surrounding subblocks. It generally has a synclinal structure (Plate 2; cross sections D–D′, E–E′, F–F′, and G–G′) whose trough is generally covered by thick Quaternary terraces. The thickest Miocene section in the Hammam Faraun block was laid down in this structural basin at Gebel Sarbut El Gamal and the area east of Gebel Hammam Faraun.

CHARACTERISTICS OF THE HAMMAM FARAUN BLOCK

Based on the structural relations discussed above, the Hammam Faraun block is characterized by the following features:

1. It generally has a NE direction of dip; dip angle ranges from 12° to 20°.
2. It is bounded on the east, west, and south by major faults. The northern boundary lies close to the change in dip regime in the northern part of the Suez rift and will be the subject of another detailed study.
3. The western boundary fault (the Hammam Faraun Fault) has a NW orientation and 4800 m throw (Moustafa & El Shaarawy 1987). It consists of several NW and NNW-oriented segments.
4. The eastern boundary coincides with the rift-bounding fault and has a zigzag pattern and 1300–1850 meters throw. It consists of NNW and NNE-oriented fault segments. The NNW-oriented faults are listric.
5. The southern boundary is oriented ENE to E-W and its throw definitely exceeds that of the eastern boundary fault.
6. The Hammam Faraun block includes several subblocks, some of which have anomalous direction(s) of dip, e.g. the Wadi Taiyba, Gebel Matulla, and Gebel Sarbut El Gamal subblocks.
7. The north-central part of the Hammam Faraun block is an open syncline which has the lowest structural elevation in the block.
8. The block is dissected by NW, NNW, NNE, and E-W-oriented faults (Fig. 4). The NW and NNW-oriented faults have very steep angles of dip while the NNE-oriented faults generally have angles of dip less than 60°.
9. The NW-oriented faults are both normal and diagonal-slip. The latter have major dip-slip (normal) components and subordinate right-lateral strike-slip components. On the other hand, the NNW-oriented faults are only normal while the NNE-oriented faults are both normal and diagonal-slip. The latter have major dip-slip (normal) components and subordinate right- or left-lateral strike-slip components (Fig. 5).

10. The structural deformation of this block took place at two different episodes. The main faulting was apparently contemporaneous with the intrusion and extrusion of the Oligo-Miocene (22–24 m.y. old (Steen 1982)) mafic igneous rocks. Major displacements on these faults took place before the deposition of the Lower Miocene Nukhul Formation. The second movement took place after the deposition of the existing part of the Rudeis Formation.
11. Limestone boulders in the conglomerate beds of the Abu Zenima Formation (some of which are angular) are derived from older Eocene and Cretaceous rocks (especially in the Wadi Nukhul area). These conglomerates indicate the existence of some relief at the time of their deposition where the older rocks were at a relatively higher position. This relief could either be related to the Late Eocene fall in sea level (Haq *et al.* 1987) or due to a structural relief. If the latter possibility turns out to be correct, it is not improbable that they may be related to an early phase of rifting during the time of deposition of the Abu Zenima Formation. Further work in the surrounding areas is needed before this statement is accepted.
12. Local folding in the Hammam Faraun block is associated with nearby faults. Synclines exist on the downthrown sides of these faults while anticlines exist on the upthrown sides.

TILTING OF THE HAMMAM FARAUN BLOCK

1. *NE dip direction*

The rift-bounding fault forms the eastern boundary of the Hammam Faraun block and separates it from the rift shoulder that generally has a horizontal attitude. The tilted rocks of the Hammam Faraun block dip toward the NNW-oriented segments of the rift-bounding fault indicating that these fault segments are listric. Rotation of the downthrown sides of these listric faults is proposed to be the cause of the predominant NE dip of the Hammam Faraun block.

Listric normal faults may have limited rotation of the downthrown block when the throw is relatively small. In this case, the beds retain their original attitude a short distance from the fault. This leads to the formation of a rollover anticline (Bruce 1973) (Fig. 7A). Local drag close to the fault itself is expected to take place (Fig. 7B). These relations are in harmony with similar observations in the western Colorado Plateau (Hamblin 1965).

In most cases, the crest of the rollover anticline is dissected by normal faults that form a graben(s) and/or step fault arrangement (Fig. 7C). These normal faults are formed by layer-parallel extension due to the bending at the crest of the fold. The Gebel Abu Ideimat subblock is a good example of a rollover anticline with collapsed crest. It was formed by rotation on the downthrown side of a listric normal fault.

2. *Horizontal (non-rotated) rocks in the Hammam Faraun block*

The Gebel Matulla subblock generally has a horizontal attitude. Close to the rift boundary in this area, the southern part of the Gebel Sarbut El Gamal subblock has a SW-dipping graben bounded on the east by the rift-bounding fault and on the other sides by an arcuate fault system.

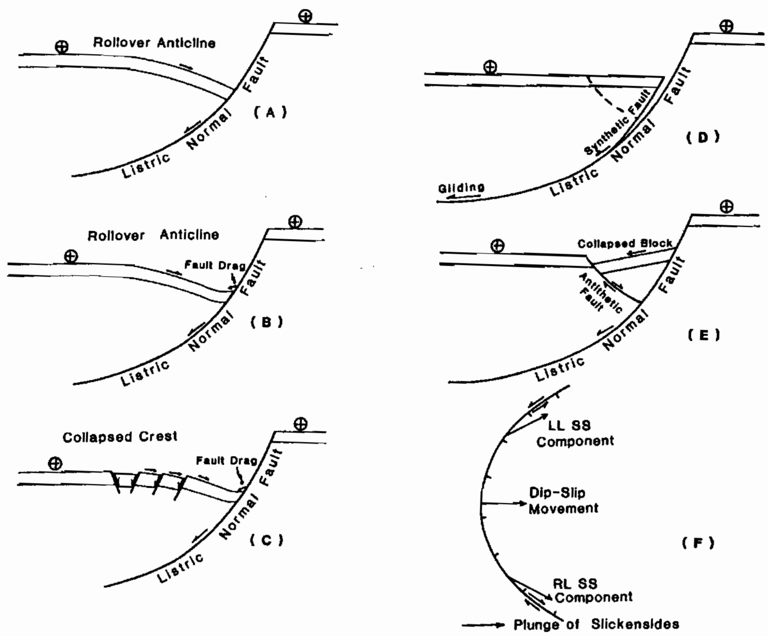

Fig. 7. (A) Rollover anticline formed by displacement on a listric normal fault. (B) Rollover anticline with fault drag close to the main listric fault. (C) Rollover anticline with collapsed crest. (D) Gliding on the very gently dipping segment of a listric normal fault. (E) Formation of a collapsed block with anomalous dip direction. (F) Map view of the spoon-like antithetic fault bounding the left-hand side of the collapsed block shown in (E). Modified after Hamblin 1965.

The model proposed to account for these anomalous dips assumes that the listric fault at the rift boundary in this area flattens at a relatively shallow depth and the downthrown block is detached from the foot wall at that shallow depth. This detached block glides on the lowermost very gently-dipping to horizontal segment of the fault leading to non-rotation of the downthrown block (Fig. 7D). Unstable conditions would exist at the edge of the downthrown block as a hanging block would exist and is pulled down by the effect of gravity.

The collapse of this hanging block would very probably take place along a curved fault of arcuate map view. This fault is antithetic to the rift-bounding fault and is proposed to be curved (listric) in cross section leading to the rotation of the collapsed block (Fig. 7E and Plate 2, cross section B–B′). A nearly similar model was proposed by Hamblin (1965) in the western Colorado Plateau although he does not consider the antithetic faults to have curved cross sections. The displacement on the different parts of the spoon-like antithetic fault would cause the development of dip-slip as well as diagonal (both right- and left-lateral) slickensides (Fig. 7F).

Close to the collapsed block, the rest of the glided block retains its horizontal attitude and is expected to be underlain, at a relatively shallow depth, by a long horizontal segment of the rift-bounding, listric, normal fault. The horizontal Gebel Matulla subblock is bounded on the north and south by monoclines (the Wadi Darat, Wadi El Khaboba, and Wadi Nukhul monoclines) (Fig. 3). These monoclines face the surrounding subblocks (Wadi Taiyba, North-central, and Wadi Nukhul subblocks). They are proposed to overlie deep-seated (basement) faults which

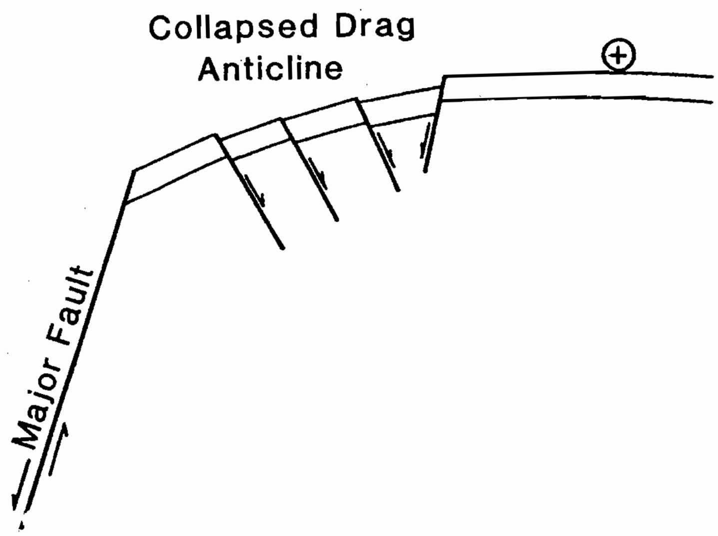

Fig. 8. Fault drag anticline with collapsed crest on the upthrown side of a major normal fault.

connect the flat segments of the rift-bounding listric normal fault. This fault is proposed to detach at a relatively shallow depth beneath the Gebel Matulla subblock and at relatively deeper depths to the north and south.

3. *Local SW dip*

The western part of the Wadi Taiyba subblock has a predominant SW dip which contrasts with the dip of the surrounding subblocks. The origin of this anomalous dip direction is most probably related to drag on the upthrown side of the major NW-oriented Hammam Faraun fault whose throw is 4800 m (Moustafa & El Shaarawy 1987). This remarkable drag forms a fault drag flexure on the upthrown side (Ragan 1973, p. 137). The crest of this flexure is collapsed by normal faults formed by layer-parallel extension. These faults form a graben and step fault arrangement (Fig. 8; Plate 1; and Plate 2, cross section D–D′).

Gebel Musabaa Salama shows similar structural relations. It lies on the upthrown side of a major normal fault (rift-bounding fault) and forms a fault drag flexure with collapsed crest (Plate 1).

The Wadi Taiyba subblock and Gebel Musabaa Salama show the deformation of parts of the foot walls of major normal faults. They may represent "excursions" of the major faults into the foot walls.

ANALYSIS OF THE FAULT SETS

The NW, NNW, and NNE-oriented faults are among the predominant fault sets in the Hammam Faraun block. Field evidence indicates that these faults are contemporaneous. A major NW-oriented fault exists at the westernmost side of the Hammam Faraun block (Hammam Faraun fault) and was proposed by Moustafa & El Shaarawy (1987) to have existed before the Neogene opening of the Suez rift.

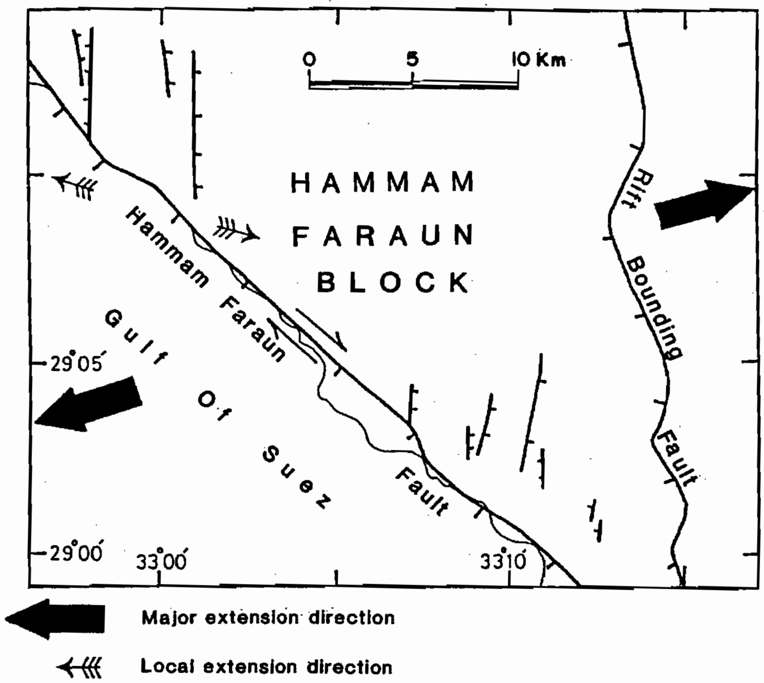

Fig. 9. Model of formation of N-S to NNE-oriented faults in the Hammam Faraun block. See text for explanation.

Garfunkel & Bartov (1977) indicated that the Suez rift was formed by ENE-oriented extension in the Oligocene time. This extension led to the formation of the NNW-oriented normal faults and the rejuvenation of pre-existing fractures. Therefore, the NW-oriented Hammam Faraun fault was rejuvenated as a diagonal-slip fault with a predominant dip-slip (normal) component and a subordinate right-lateral strike-slip component as it is not exactly perpendicular to the direction of extension. Field data (Fig. 5) indicate that the NW-oriented faults of the Hammam Faraun block are either normal or right-lateral diagonal-slip. The right-lateral strike-slip component on the Hammam Faraun fault would cause a local E-W to ESE-WNW-oriented extension (Fig. 9). Under the effect of this local extension, the Hammam Faraun block yielded by rupture along N-S to NNE-oriented normal faults at its western boundary.

CONCLUSIONS

1. The predominant NE direction of dip of the Hammam Faraun block apparently resulted due to rotation of the downthrown sides of NNW-oriented listric normal faults at the eastern boundary of the Suez rift.
2. Rollover anticlines form by limited rotation on listric normal faults of relatively small displacement.
3. Local departures from the predominant NE direction of dip in the Hammam Faraun block are not uncommon. The horizontal Gebel Matulla subblock and the associated graben at the southern part of the Gebel Sarbut El Gamal sub-

block apparently indicate gliding on the gently dipping segment of a shallow-detachment, listric, rift-bounding fault in that area. The graben contains a small SW-dipping block.

4. Local SW dip in other parts of the area is related to drag on the upthrown sides of major faults.
5. Local intrasubblock extension results from layer-parallel extension at the crests of rollover and fault-drag anticlines and is relieved by normal faulting at the crests of these folds.
6. Subordinate folding in the Hammam Faraun block is caused by the drag on major normal faults. Drag on the downthrown sides is more frequent compared to drag on the upthrown sides.
7. The ENE-WSW-oriented extension that opened the Suez rift in the Oligo-Miocene time was accompanied by the extrusion and intrusion of mafic igneous rocks in the Hammam Faraun block. It led to the formation of the NNW-oriented normal faults and the rejuvenation of a NW-oriented pre-rift (pre-existing) fault at the western boundary of the Hammam Faraun block (the Hammam Faraun fault).
8. The Hammam Faraun fault was rejuvenated as a diagonal-slip fault with a major dip-slip (normal) component and a subordinate right-lateral strike-slip component.
9. N-S to NNE-oriented normal faults were formed by the local extension resulting from the right-lateral strike-slip component on the Hammam Faraun fault. They exist close to this fault.
10. The main faulting of the Hammam Faraun block was apparently contemporaneous with the intrusion and extrusion of the Oligo-Miocene mafic igneous rocks. The movement on these faults took place at two different episodes. The older occurred before the deposition of the Nukhul Formation, while the younger occurred after the deposition of the existing part of the Rudeis Formation. An early faulting phase might also have taken place during the deposition of the Abu Zenima Formation.

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الوضع التركيبي لكتلة حمام فرعون ، الجزء الشرقي لأخدود السويس

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ص . ب . ٥٩٦٩ ،
الصفاة ١٣٠٦٠ ،
الكويت

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جمهورية مصر العربية

خلاصة

أوضح التخريط الجيولوجي لكتلة حمام فرعون بالجزء الشرقي من أخدود السويس اتجاه الميل السائد ناحية الشمال الشرقي مع وجود محلي لبعض الميول الأخرى المخالفة . وقد اكتسبت الصخور ميلها السائد بدورانها حول صدوع عادية مقوسة اتجاهها ش غ ، ش ش غ عند الحد الشرقي لأخدود السويس . وتوجد منطقة صخورها أفقية ويبدو أنها قد تحركت على الجزء السفلي القليل الميل لصدع مقوس . أما عن الميل المحلي الجنوب غربي بالمنطقة فهو نتيجة السحب على صدوع كبيرة الرمية .

وبينما يلعب الطي دورا ضئيلا في كتلة حمام فرعون فان التصدع هو التركيب السائد . وأطقم الصدوع السائدة اتجاهها ش غ ، ش ش غ ، ق ـ غ ، ش ش ق . وتوضح الخدوش الموجودة على أسطح الصدوع أن الصدوع الشمال غربية عادية أو ذات تزيح منحرف يميني ، أما الصدوع الشمال شمال غربية فهي عادية فقط ، بينما الصدوع الشمال شمال شرقية عادية أو ذات تزيح منحرف يميني أو يساري .

وقد تسبب اتجاه الاستطالة الشرق شمال شرقي ـ غرب جنوب غربي بأخدود السويس في تكوين الصدوع الشمال شمال غربية وتجدد الحركة على صدع قديم اتجاهه شمال غربي عند الحافة الغربية لكتلة حمام فرعون (صدع حمام فرعون) ليصبح له تزيح منحرف يميني . وقد سببت مركبة الحركة الأفقية اليمينية على هذا الصدع وجود استطالة محلية بجوار الصدع أدت إلى تكوين مجموعة الصدوع العادية المتجهة ش ـ ج إلى ش ش ق .

وقد بدأ تكوين الأخدود بكتلة حمام فرعون قبل ترسيب تكوين نُخُل (الميوسين السفلي) ثم تجددت الحركة بعد ترسيب الجزء الموجود من تكوين الروديس .